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Interaction between proprioceptive sensitivity and the attentional demand of dynamic postural control in sedentary older adults

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Résumé

Les chutes chez les personnes âgées ont été attribuées à une baisse de la fonction proprioceptive ainsi qu'à une incapacité à allouer suffisamment d'attention au maintien de l'équilibre dans des conditions multitâches. Cette étude vise à explorer l'interaction entre les demandes proprioceptive et attentionnelle du contrôle postural dynamique de la personne âgée. Des adultes sédentaires âgés et jeunes ont effectué une tâche de limite de la stabilité posturale avec et sans vision ainsi qu'une tâche attentionnelle secondaire de soustraction mathématique (n-3). Ces deux tâches étaient effectuées soit seul (tâche simple) ou simultanément (tâche double). La force de réaction au sol a été collectée à 200 Hz en utilisant une plateforme de force AMTI et les déplacements des centres de pression (COP) ont été analysés. Les limites fonctionnelles de la stabilité ont été quantifiées comme l'excursion maximale du COP pendant l'inclinaison volontaire du corps dans chaque direction. Nous avions émis l'hypothèse que les plus grandes différences liées à l'âge seraient observées dans la condition de tâche double en raison des limitations des ressources attentionnelles pour faire face simultanément à des exigences proprioceptives et cognitives élevées. Nos résultats indiquent que l'addition de la tâche attentionnelle n'a pas influencé les limites de stabilité posturales des participants. Cependant, les personnes âgées ont significativement diminué leur performance dans la tâche attentionnelle lorsqu'ils ont effectué simultanément la tâche posturale, particulièrement en l'absence de vision. Ces résultats supportent l'idée d'une interaction entre les demandes proprioceptives et attentionnelles du contrôle postural dynamique chez la personne âgée.

Mots-clés : proprioception, attention, contrôle postural, vieillissement

Abstract

Falls among seniors have been attributed to declines in proprioceptive function as well as an inability to efficiently allocate attention to balance in multi-task conditions. This study aims to explore the interaction between the proprioceptive and attentional demands for dynamic postural control in seniors. Old and young sedentary adults performed a postural stability limit task with and without vision as well as a secondary attentional subtraction task (n-3). These two tasks were performed either alone (single task) or simultaneously (dual-task). Ground reaction force was collected at 200 Hz using an AMTI force platform and centre of pressure (COP) was analyzed. The functional limits of stability were quantified as the maximum COP excursion during voluntary leaning in each direction. We hypothesized that the greatest age-related differences would be seen under the dual-task condition because of limitations in attentional resources available for concurrently coping with high proprioceptive and cognitive demands. Our findings indicated that the stability limits of both subject groups were not influenced by the addition of the cognitive attentional task. However, seniors markedly decreased their performance in the cognitive task while simultaneously performing the postural task and this trend was accentuated in the absence of vision. These results support the idea of an interaction between the proprioceptive and attentional demands of dynamic postural control in seniors.

Key words: Proprioception, attention, postural control, aging, dual-task, motor control

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List of Abbreviation

APA: Anticipatory postural adjustments

COP: Center of pressure

MoCA: Montreal Cognitive Assessment

RMS: Root mean square

SOA: Sedentary older adults

SYA: Sedentary younger adults

To you, Nagymama, because you’re a living testament of what anyone can achieve if they work hard

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CHAPITRE 1—Introduction

Older adults currently represent the fastest growing population. Demographic trends predict that by 2036, more than one out of four Canadians will be aged 65 years and older (Census Canada, 2016). Unfortunately, this gain in lifespan has also been accompanied by an increase in the cost to our health care system as a result of falls (PHAC, 2014).

Approximately 30% of seniors aged 65 years and older are predicted to fall each year, with this amount increasing in older seniors over the age of 80 (PHAC, 2014). Falls may lead to fear of falling, restriction of everyday activities, injuries and a litany of complications (Statistics Canada, 2014). Falls therefore act as an accelerating agent in the decline of older adults functional health, autonomy, and ultimately quality of life. Thus, understanding the barriers of healthy aging is pivotal to promote an active engagement in the life of seniors.

To combat this growing issue, we must first understand the myriad of factors surrounding falls in older adults. One major aspect to prevent balance disturbances and falls is the ability to perceive the limits of postural stability (Blanchet et al., 2014). Such limits correspond to the maximum range in which the centre of body mass can be moved safely without changing the base of support (Horak, 1987). The perception of stability limits requires the processing and integration of multiple sensory modalities including visual, vestibular and also importantly, proprioceptive signals (Holbein-Jenny et al., 2007). Proprioception or the sense of body segments position and motion relative to one another is a critical source of sensory information for everyday motor activity. Not surprisingly, a wealth of literature has underscored the vital role of proprioception in controlling voluntary movements and in maintaining postural stability (Amiridis et al., 2003; Messier et al., 2003). Of particular interest, growing evidence in the field of motor neuroscience suggests that declines in proprioceptive function represent a fundamental aspect of the aging process (Goble et al., 2009). Notably, reduced proprioceptive acuity in seniors has been identified as a key-contributing factor to an increased likelihood of falls (Goble et al., 2009).

Over the last decade, numerous studies indicated a relationship between the aging of cognitive and sensorimotor functions (Doumas et al., 2009; Boisgontier et al., 2013b; Henry and Baudry, 2019). One line of evidence for this comes from studies demonstrating a substantial decline in postural stability when seniors are faced with a dual-task situation, i.e. when older adults are required to perform a primary postural and a secondary cognitive attentionally demanding task concurrently (Woollacott and Shumway-Cook, 2002). Such findings suggest: a) that postural and cognitive tasks share common attentional resources and b) that the control of posture is less automatic or more attentionally demanding in older than in young adults, particularly during challenging balance and cognitive tasks (Boisgontier et al., 2013a).

In this thesis, we investigated, for the first time, whether increased attentional load during a complex dynamic proprioceptive-dependant task influences postural stability limits in seniors. Understanding this potential interaction is crucial, considering declines in proprioceptive function and attentional resources have been both associated with fall risk in seniors. By clarifying the link between attention and proprioception for postural control, the current master's thesis project will expand the current knowledge on the mechanisms by which postural instabilities occur in seniors. This is essential to develop relevant interventions to prevent falls and promote global healthy aging.

CHAPITRE 2—Literature Review

Anterior studies have suggested a possible interaction between proprioceptive acuity and the attentional demand required for adequate postural control in older adults. However, this interaction has yet to be systematically investigated. Leaving us with a hole in the literature, the main interest of the following literature review is to identify studies that have examined proprioception and attention in the context of postural control in our aging population. This theoretical framework will focus on the impacts normal aging has on postural control, attention and proprioception, as well as identify studies that have attempted to understand the relations between these key factors. Questions addressing how age effects our postural control and attentional resources will first be established, followed by the impacts of age-related declines in proprioception on our postural control and attention. Finally, the last section of this review will aim to highlight the key findings made by recent studies that have suggested a possible interaction between these vital aspects.

2.1—Normal Aging

2.1.1—Living longer, but not healthier lives

One out of four Canadians is expected to be aged 65 years and older by 2036, designating older adults as the fastest growing population in Canada (PHAC, 2014). Over the course of the last century, the average life expectancy has significantly increased from 57 to 82 years. Although encouraging for many aging adults, this gain of almost 25 years in longevity is unfortunately not always accompanied by a high quality of life and independence. Indeed, evidence has demonstrated that the functional health i.e., the ability to successfully accomplish activities of daily living significantly declines after the age of 65 (Decady & Greenburg, 2014). As our functional health declines, our reliance upon others for the accomplishment of our basic needs grow. This has been highlighted in recent studies demonstrating that the number of independently lived years drops significantly after the age of 75 (Statistics Canada, 2011b). This lack of autonomy and increase in dependence upon others for simple activities of daily living has been associated with a low quality of life and sense of happiness among seniors (Census Canada, 2016). We are therefore living longer lives, but not necessarily living them well. Thus, identifying the modus operandi for healthy aging is of paramount importance to our aging population.

2.1.2—Falls in the elderly

Falls are a major adversary to functional health. One out of three seniors aged 65 years and older are predicted to fall each year, with this amount increasing in older adults over the age of 80 (PHAC, 2014). Falls are directly responsible for 95% of all hip fractures among older adults, of which 20% result in death within the following year (PHAC, 2014). Acting as the number one cause of injury-related hospitalizations among seniors, falls are among the greatest points of risk for a loss of independence in older adults (Statistics Canada, 2014). Research has demonstrated that more than one third of seniors, who were hospitalized due to a fall, were later discharged to long-term care facilities (Statistics Canada, 2011b). Falls represent a catalyst in older adult's loss of autonomy and functional health (PHAC, 2014). Fall prevention has therefore become a crucial area of investigation in todays scientific research field.

2.2—Postural Control

2.2.1—Quantifying and understanding the role of postural control through the functional limits of stability

Postural control is a critical aspect of nearly all activities of daily living (Alexander, 1994, Muir et al., 2013). It is a person's ability to maintain stability of the body and it's segments in response to forces that disturb the body's structural equilibrium (Horak et al., 1989). Postural control is achieved through a set of complex mechanisms (e.g., sensory integration, motor command generation, and muscle contraction) that stabilize the body by keeping the center of mass within the base of support (Diener et al., 1988; Horak et al., 1989).

The center of pressure (COP) is an indirect measure of postural sway that allows us to quantify a person's ability to maintain balance (Ruhe et al., 2011). Perturbations to stance induced by the external environment and our own movements cause shifts in our centre of pressure, beyond our stability limits (Paillard, 1976; Horak, 1987). When we surpass these limits, while leaning forward or picking up something off the ground, it is our ability to control posture that prevents us from losing balance and sustaining a fall. In order to avoid falling or losing balance, the central nervous system must continuously integrate different sources of sensory information, while generating the appropriate motor commands to perform these balance corrections (Diener & Dichgans, 1988).

One approach to quantify postural control is measuring the limits of stability (Huo, 1999; Holbein-Jenny et al., 2007; Mancini et al., 2008). The limits of stability is best described as the maximum distance an individual can voluntarily displace their centre of pressure, while leaning in a given direction, without losing balance (Horak et al., 2005; Melzer et al., 2008). It is a powerful paradigm to investigate daily life postural skills, as it simulates the functional positions that occur in everyday actions. It has also been suggested to be an important prerequisite for the successful planning and execution of postural movements (Melzer et al., 2008). For instance, maintaining the center of pressure near the forward or backward limits of the foot support simulates the transition from stance to gait and from sit to stand (Newton, 2011); situations where fine postural control is necessary to prevent a fall (Montero-Odasso et al., 2012).

Importantly, quantifying the limits of stability has been considered a more sensitive measure in comparison to frequently used clinical tests and analyses of postural sway in identifying balance impairments and fall risk in older adults and in neurodegenerative diseases (Huo, 1999; Mancini et al., 2008; Blanchet et al 2014; Faraldo-Garcia et al., 2016).

2.2.2—Postural control as we age, and the risk of falls

Age is accompanied by a progressive deterioration of our ability to maintain postural control (Horak et al., 1989). Studies have highlighted that in both static (Benjuya et al., 2004; Huxhold et al., 2007; Blaszczyk et al., 2016) and dynamic conditions (Doumas et al., 2008; Ko et al., 2015; Kasahara et al., 2015), older adults experience decreased stability when compared to younger adults. Furthermore, both greater postural sway and an increased incidence of falls have been observed in older adults, suggesting a slowing in the detection and correction of postural disturbances (Sheldon, 1963; Stelmach and Worringham, 1985). Age-related changes have also been associated with decreased limits of stability (Holbein-Jenny et al., 2007; Schieppati et al., 2014; Kasahara et al., 2015), declines in muscle strength (Lexell et al., 1988) and foot sensation (Melzer et al., 2004). Combined, these findings highlight some of the various aspects that have been documented in the literature underscoring deficits in postural control as a result of the aging process.

The major consequence arising from the above-mentioned deficits to postural control in older adults are falls. Within the last decade, a plethora of studies have examined how postural control degrades in seniors (see Alexander, 1994 for a review), in an attempt to uncover ways in which we might help understand and prevent this issue. Declines in proprioceptive sensitivity (Lord et al., 1991; Globe et al., 2009, Globe et al., 2011) and increases in attentional resources (see Woollacott & Shumway-Cook, 2002 for a review) have been highlighted as two key factors affecting postural control and fall risk in the aging population. These proposed elements will be further explored in the following sections.

2.3—Attention

2.3.1—Are you paying attention?

Before understanding the attentional requirements postural control might have, we must first understand how attention is implicated in our daily lives. Attention is the cognitive process by which we selectively concentrate on a specific aspect of information, while excluding any other stimuli (Kahneman, 1973). Our attentional capacity is based on our ability to process surrounding information (Kahneman, 1973). However, this processing capacity is a limited resource and we cannot always divide it equally while doing more than one task (Wright, 1981). Imagine you are at a busy intersection; your attention is drawn to the traffic light, the approaching cars and pedestrians. Your ability to cross the street safely is fundamental to your independence. Such a complex situation requires flexibility in allocating your attentional resources between maintaining your discussion with the person beside you, while still performing other crucial motor tasks (i.e.: turning your head to check the light and the on-coming traffic, walking across the street). These tasks must be done concurrently, without compromising the performance of either one. Therefore, when performing any two tasks simultaneously that require more than the total capacity of available attentional resources, the performance in one or both might deteriorate (Shumway-Cook and Woollacott, 2000). It is therefore important to understand that limits in attentional resources can have a significant impact on our ability to perform daily tasks, and that deficits to our attentional resources can greatly impact our functionality (Wickens, 1989).

2.3.2—Attentional resources as we age: automaticity across the lifespan

As we age, the efficiency of our attentional resources degrades (Teasdale et al., 1993). More specifically, older adults demonstrate a slowing in certain cognitive processes related to attention (Cerella 1985; Salthouse 1996). Despite whether this generalized cognitive slowing is due to slower synaptic transmission, increased information loss, or greater neural noise, the conclusive result is that all tasks that measure attention by how fast people can respond show at least some evidence of age-related slowing (Faust et al., 1999; Verhaeghen, 2011).

The performance of two concurrent tasks in the context of a dual-tasking paradigm has been cited as being particularly sensitive to the effects of age (Verhaeghen 2011), especially when task-complexity is high (Boisgontier et al., 2013a). As a result, previous studies have used dual task design to examine executive functions and more specifically to assess, the attentional resources allocated to a task of interest (Della Sala et al., 1995). In order to accomplish higher complexity tasks, automaticity of a mental process is used to evoke several favourable aspects including an overall better performance strategy when faced with multiple complex tasks (Muller-Townsend, 2017). Despite evidence by Rogers and Fisk (2001) demonstrating that older adults could improve performance on novel tasks with practice, the speed at which they would achieve such remains relatively slow when compared to young controls. Furthermore, older adults reportedly lose the ability to automatize novel tasks (Maquestiaux et al., 2013). Such a response in older adults to multi-tasking cannot be explained by the simple "generalized cognitive slowing" of certain cognitive processes related to attention, but rather appears to indicate a genuine age-related deficit in the acquisition of new task automaticity (Maquestiaux et al., 2013). Unfortunately, motor skills specifically (i.e. postural control), have been found to be automatic in young and middle aged people, but require more attentional resources in older adults. This is a result of compensation due to deficits in motor skills among the elderly (Rogers and Fisk, 2001). But at what cost do such deficits come?

2.3.3—Attentional resources in the control of posture as we age: concentrating to avoid falling

Postural control has traditionally been considered an automatic controlled task involving limited attentional resources (Reilly et al., 2008). Contrary to this assumption, a growing body of literature over the last decade has now identified postural control as having significant attentional requirements dependent on the postural task and the age of the individual (Boisgontier et al., 2013a).

Although some literature has recently highlighted that both young and older adults use similar strategies for postural control (Potvin-Desrochers et al., 2017), simply assuming that there are no age-related alterations is not sufficient. Indeed, a study by Geerlings and colleagues (2014) using magnetic resonance imagining (MRI), reported that older adults could select relevant information just as well as young adults, but that they recruited additional neural connectivity in order to perform the task at the same level as young adults. Such evidence underscores the involvement of compensatory processes during aging attempting to normalize deficits in attentional resources.

Dual-task paradigms, as previously described, allow us to observe and understand alterations to our attentional capacity (Doumas et al., 2008). Conventionally, it was believed that, with age, our cognitive and sensorimotor functions were two separate evolving phenomena that functioned as two independent parallel systems (Huxhold et al., 2006). However, a number of recent studies have demonstrated that the two systems are not as segregated as originally assumed (Andersson, 1998; Boisgontier et al., 2013). Attention becomes increasingly engaged as sensory conflicts arise in older adults (Redfern et al., 2001), and may be particularly important in more complex tasks involving postural control, such as in the presence of external perturbations (Redfern et al., 2001). For example, in older adults it has been demonstrated that the addition of a cognitive task causes a substantial deficit to postural stability (Huxhold et al., 2006) relative to young adults. Such evidence indicates that conscious rather than automatic processes might be at work in these older individuals. According to Melzer and colleagues (2001), it is likely that older adults require increased conscious attention to maintain postural control for a given postural task, and therefore have fewer attentional resources to allocate to the cognitive task being simultaneously performed. In other words, older adults are concentrating to avoid falling. Understanding the circumstances under which the amount of conscious control increased during the course of aging and how this affects postural and cognitive performance is an important question that remains largely unanswered.

Importantly, decreases in the attentional resources available have been recognized as fall predictors in older adults (Faulkner et al., 2007; Montero-Odasso et al., 2012). Previous studies revealed the falls experienced by seniors often occurred in dual task conditions such as walking while talking (Tideiksaar, 1996). Past research has also attributed age-related declines in balance to decreases in sensory and/or motor system functions (Diener et al., 1984; Fitzpatrick and McCloskey, 1994; Fitzpatrick et al., 1994). However, research in cognition now suggests other intrinsic sources of instability, including age-related attentional allocation deficits (Laessoe et al., 2016).

A number of studies have recognized the role deficits in attentional resources can have on the postural control of older adults. In 1996, Lajoie and colleagues reported that healthy seniors needed to allocate a greater proportion of attentional resources to postural control compared to young adults. They established this through the use of a sitting, standing and walking postural task with the addition of a verbal-response reaction time cognitive task. Such evidence supports the previously mentioned idea that older adults require greater neural recruitment in order to maintain stability. Additionally, Laessoe and colleagues (2016) tested young and older subject in a dynamic anticipatory postural condition in which they had to exceed their limits of stability to touch a target with and without an added cognitive load. They found that when the primary task was more attentionally demanding, the remaining attentional capacity for processing the secondary (cognitive) task was limited, resulting in a diminished performance in seniors.

2.3.4—Dual Task Costs: quantifying the cost of attentional resources in older adults

Past literature has shown that in older adults, postural control requires attentional resources (Woollacott & Shumway-Cook, 2002). The use of a secondary attentional task in order to increase the challenge of a given postural task has therefore been frequently used (Boisgontier et al., 2011; Fraizer and Mitra, 2008; Lacour et al., 2008). When two tasks (i.e., posture and attention) are performed simultaneously (dual-task), they demand more than the total amount of available resources (Doumas et al., 2009). As a result, dual-task costs (DTCs) can be observed, as the performance of either task or both declines. Given that older adults' overall resources are reduced relative to young adults' and that sensorimotor control declines with age (Lindenberger et al., 2000; Woollacott and Shumway-Cook, 2002), the dual-task costs in older populations is expected to be higher.

Current aging research has attempted to gain insight into the way resources are allocated by assessing sensorimotor-attentional dual-task performance (Doumas et al., 2009; Li et al., 2018). Through sensorimotor tasks such as posture (Doumas et al., 2008) and walking (Lovden et al., 2008; Lundin-Olsson et al., 1997), various studies have quantified the cost diminished attentional resources can have on cognitive task performance. Posture is of particular interest for aging research as lack of control in this task increases the possibility of sustaining a fall (Fuller, 2000).

Dual-task costs (DTCs) express the effects of the additional costs imposed on individual-task performance in a dual-task setting (Brustio et al., 2017). DTCs are expressed as a percentage of single task performance and can indicate potential deficits in resource allocation (Doumas et al., 2009). Cognitive task selection therefore plays a pivotal role in the age-related dual-task costs of older adults. Importantly, dual-task costs may not only demonstrate deficits in attentional resource allocation, but as well be an indicator of potential impairments of everyday life activities that require us to divide our attention.

2.3.5—Compensatory mechanisms: The impact of task selection on dual-tasking and resource allocation in older adults

Previous literature has highlighted the involvement of cognitive resources during postural tasks and the dependency of automatic and higher-level cognitive processes (Rankin et al., 2000; Laessoe et al., 2016), particularly in advancing age. Past research has also suggested that the pattern of resource allocation in older adults is characterized by giving greater priority to the task with the greater importance, in this case postural control, due to the high prevalence of instabilities and falls (Fuller 2000, Simoneau et al., 2008). The 2008 study, conducted by Doumas and colleagues observed a decrease in cognitive task performance in dual- versus single-task conditions while using an n-back cognitive task with varying somatosensory conditions. These same changes were however not observed while participants stood on a stable surface, which allowed older adults to accommodate cognitive task performance. In the n-back task, a continuous performance task involving working memory, participants are presented a series of visual stimuli. They are then asked to identify whether it matches a stimulus n trials prior for each stimuli (Kirchner, 1958). Doumas and colleagues study (2008) showcased the flexible nature of attentional resource allocation in the elderly as well as the importance of choosing a cognitive and postural task sensitive enough to highlight age-related changes in varying experimental conditions.

In the current study we required a task that could be done simultaneously with a postural task in conditions where sensorimotor information could be manipulated (i.e. eyes open or eyes closed conditions). Although challenging, an n-back task would require visual information to be provided. Counting is an alternative cognitive task that has been frequently used (Maylor and Wing, 1996; Wu et al., 2013; Ghai et al., 2017), but allows the participant to regulate their own pace and can therefore be a limiting factor in performance across participants, as the task is not continuous. The use of a subtraction task however, allows us to control both the parameters of the task, while occupying the participant’s attention continuously (i.e. due to timed interval of recorded digits) and has been shown to be sensitive to age-related changes. Using a serial subtraction task of 3 and 7, Srygley and colleagues (2009) showed that a walking task might alter the cognitive performance of individuals. Importantly, this alteration was more pronounced in older adults compared to young adults as indicated by the decrease in their cognitive performance (i.e. greater amount of errors made).

Older adults are essentially able to handle a postural dual-task as well as their younger counterparts; however, there is a clear (but often non-significant) trend toward greater postural DTCs in older versus younger adults. When the difficulty of the postural task is increased in dynamic conditions, studies show that either the concurrent task performance (Rapp et al., 2006; Srygley et al., 2009), the postural performance (Doumas et al., 2009; Redfern et al., 2001; Smolder et al., 2010) or both (Doumas et al., 2008; Shumway-Cook and Woollacott, 2000) are more affected in the older adults compared to younger adults. Understanding the shift from this maintained to decreased performance of either the postural or cognitive task seen in older adults when compared to young adults requires further examination. Additionally, investigation in to the mechanisms of compensation used by older adults to maintain certain levels of performance comparable to young adults merit further inquiry.

Current works have aimed to better understand such mechanisms of compensation. Lajoie and colleagues (2017) suggested that the performance of continuous cognitive tasks while standing promotes the automatization of postural control in both young and older adults. This explanation was based on results, which demonstrated increased postural stability and decreased sway in the older participants that performed the dual-task (in comparison to younger participants). Such suggests older adults develop compensatory mechanisms (ex: such as increased neural activity), in order to compensate for decreases in stability, while cognitive demand is continuously applied. However, despite this automatization seen in the study by Lajoie and colleagues (2017), older adults exhibited what appeared to be a plateau for the continuous cognitive task, while young adults further increased their postural stability. Such results indicate that regardless of the compensatory mechanisms used by older adults, there can still exist a potential priority allocated to posture for seniors when they're performing real life tasks involving varying loads of attentional demand.

2.4—Proprioception

2.4.1—Proprioception, our sixth sense

Proprioception encompasses both our sense of limb movement and limb position (Bekkers et al., 2014). It is an essential sensation used in everyday motor activity and its contribution increases when our limbs are not in view (Globe et al., 2009). Proprioceptive sensation arises primarily from muscle spindles but also from mechanoreceptors and cutaneous sources (Suetterlin et al., 2013). Mediating this perception of movement and limb position, muscle spindles provide essential proprioceptive feedback to the central nervous system (Clark et al., 1985). Proprioceptive feedback is required to adapt motor commands in response to alterations in the biomechanical properties of our limbs (Bekkers et al., 2014). An abundance of literature has highlighted the importance of proprioceptive feedback in the control of posture and voluntary movements (Skinner et al., 1984; Riemann, 2002). Patients lacking proprioceptive sense due to large fibre neuropathies exhibited profound deficits in inter-joint coordination (Sainburg et al., 1995), force control (Rothwell et al., 1982), performance of targeted movements (Sanes et al., 1984; Messier et al., 2003), discrimination of object weight and shape (Rothwell et al., 1982), postural stability as well as in gait (Lajoie et al., 1996; Suetterlin et al., 2013). Notably, loss of proprioceptive acuity has often been associated with increased dependence on visual information (Jeka et al., 2010; Franz et al., 2015). Therefore, varying the availability of visual information increases the demand for proprioceptive processing and is considered as a meaningful way to assess proprioceptive functions (Henry and Baudry, 2019).

2.4.2—Effects of normal aging on proprioception and the implications on postural control

Growing evidence now suggests that declines in proprioceptive function play a fundamental role in the aging process (Henry and Baudry, 2019). Deteriorations of lower limb position sense (Lord et al., 1991,1999; Petrella et al., 1997; You, 2005; Adamo et al., 2007; Westlake et al., 2007) and motion sense (Kokmen et al., 1978; Barrack et al., 1983, Skinner et al., 1984) along with a general decline in motor performance (Baudry et al., 2010) have all been observed in studies comparing old and younger participants. Notably, alterations in muscle spindles and their afferents were found to influence not only proprioceptive perception but also more importantly postural control in older adults (Globe et al., 2011; 2012). In order to retain a stable standing position, approximately 70% of the information we process is derived from our somatosensory system (Horak et al., 2006). Therefore, maintaining adequate somatosensory function is crucial for functional aging related to postural stability (Globe et al., 2009)

Several studies have used different postural paradigms linking proprioceptive acuity with postural stability in the elderly (Simoneau and Teasdale, 2001; Doumas et al., 2008; 2009). In a study done by Lord et al. (1991), older participants performed an upright stance on ”foam” and “no foam” surface with static and dynamic aspects of stability. Sway was measured in both eyes open and eyes closed conditions. The integration of the foam was used to alter the proprioceptive input the participants could use to maintain postural stability. In that study, postural performances were positively correlated with proprioceptive acuity, thereby suggesting that proprioceptive information is vital for postural control in the elderly (Lord et al., 1991). Manipulation of sensory input can also be seen in other studies that linked postural stability and proprioceptive acuity in the elderly. In a study by Woollacott et al. (1986), unexpected perturbations through a moving platform were performed in older adults under varying visual conditions including eyes closed and visual sway referencing. When older participants were faced with functionally inappropriate visual and or somatosensory inputs, half of the group lost balance. Additionally, through the use of electromyography (EMG), an increase in the absolute latency (i.e. the delay between the stimulus and the reaction) of distal muscle responses was observed in all older adults. In a similar paradigm by Doumas et al. (2008), platform-based sway referencing was used in order to perturb proprioceptive signalling. Visual cues including visual-sway referencing were also used, causing increases in postural instability especially when somatosensory information was compromised. Importantly, sizable age differences were shown only when somatosensory information was compromised suggesting somatosensory processing for posture is sensitive to age-related decline.

Visual and ankle proprioceptive information was also manipulated in a study done by Teasdale and Simoneau (2001), in which upright posture was tested on a force platform. Muscle tendon vibration was used in this case to disrupt proprioceptive input by activating muscle spindle primary endings and producing a sensation of displacement of the solicited body segments (Teasdale and Simoneau, 2002). They concluded that postural contexts requiring reweighing of sensory inputs could lead to increased risk of balance loss. They believed such would occur as a result of insufficient attentional resources being available to allocate to postural control demands, as a result of aging.

A commonality in all studies was the conclusion that with the disruption of proprioceptive input whether through platform perturbations, muscle vibration, or visual sway referencing, there was a marked decline in older adults ability to maintain postural stability (Globe et al., 2009). Therefore, increasing the proprioceptive processing demands significantly impacted the assessment of proprioceptive acuity in older adults.

2.5—The Interaction Between Proprioception And Attention In The Postural Control Of Normal Aging

A large body of evidence, outlined above, has demonstrated that postural control is affected by both decreased proprioceptive acuity and increased attentional demand in older adults (Woollacott Shumway-Cook, 2000; Goble et al., 2009). Alterations of the proprioceptive information received from muscle spindles likely alters the efficacy of automatic processing, causing an increase in the controlled processing and the cognitive load associated with postural control (Henry and Baudry, 2019).

Shumway-Cook and Woollacott (2000) examined the ability of older adults to maintain posture on a moving platform in six varying sensory conditions while simultaneously performing a secondary reaction auditory cognitive task. Older adults experienced postural instability only when both visual and somatosensory cues for postural control were removed during the reaction time task. As participants stood on a moving platform (moving anterior and posteriorly), changing the availability of visual information did significantly increase the attentional demand associated with postural control. This suggests that when changes in surface conditions decrease the reliability of proprioceptive information, the central nervous system increases the “weight” or amount of attentional resources given to visual information for postural control. A decline in the reliability of proprioceptive information appears to be compensated, therefore, by increasing the attention on another sensory source, such as visual information (Henry and Baudry, 2019).

Similar results were found in the Redfern and colleagues (2001) study which also included dual-task conditions involving postural tasks in visually altered conditions of sway referencing, eyes closed conditions and secondary reaction time tasks. When sway-referenced visual scenes were integrated with a sway-referenced floor (altering both visual and proprioceptive information), a significant increase in reaction times could be observed. This suggests that the maintenance of balance requires more attentional resources when multiple senses are in conflict (Redfern et al., 2001). It is noteworthy that these dual-tasking deficits were accentuated in the absence of vision, when proprioceptive processing requirements were higher (Boisgontier et al., 2012, Globe et al., 2009). This suggests a link between the quality of proprioceptive sensation and attentional resources.

Further investigation was made by Doumas and colleagues (2008), using a dual-task paradigm, involving upright stance and a 3n-back cognitive task with alterations in visual cues and platform-based sway-referencing. During standing, older adults could flexibly allocate attention to accommodate the demand of the secondary cognitive task, and exhibited only slight instability. However, when instability rose through the application of compromised somatosensory information (through visual and platform sway-referencing) levels of postural control were maintained while cognitive performance declined (Doumas et al., 2008). These results highlight the flexible nature of resource allocation that is developed over the course of aging, as an adaptation to age-related declines in sensorimotor and cognitive processing (Doumas et al., 2008). They also demonstrated how disrupting proprioception might have an attentional cost on the postural control of older adults. Therefore, any alteration due to platform based sway referencing might have a direct impact on the CNS and as a result, affect information processing which is already limited by the presence of attentional resources (Wahn et al., 2017), due to the cognitive demand of the secondary task. The interaction between proprioceptive sensitivity and the attentional demand of postural control therefore warrants further investigation, as the interaction between the two aspects remains unclear, especially in populations where proprioceptive deficits already exist (Ex.: aging population, neurodegenerative populations).

The above studies highlight the importance in the choice of both the postural and the cognitive task to assess postural control of older adults in varying somatosensory conditions (Boisgontier et al., 2013). Furthermore, a commonality in these previous studies was the use of external perturbations. Very few studies have used natural internal postural perturbations that occur in daily complex whole body movements, such as leaning. A novel approach in examining the interaction between proprioception and attention in the postural control of older adults would therefore use dynamic postural conditions. Examining real-life dynamic movements would provide a better understanding of fall risk in older adults.

According to Henry and Baudry (2019), alterations in proprioceptive input from muscle spindles may reduce the efficiency of our automatic processing, thereby increasing the controlled processing and the cognitive load associated with postural control. In everyday life we do more than one action at a time, while we walk we might talk, while we stand on the metro we might read. Understanding how automatic processing might be impacted by impaired proprioception is therefore essential to the accomplishment of our daily needs. Moreover, for older adults who might already have age-related declines in their proprioceptive processing systems, understanding these processes might be crucial to preventing a fall.

CHAPITRE 3—Objectives and Hypotheses

3.1—Objectives

A major innovative aim of this project is to investigate the interaction between proprioceptive sensitivity and the attentional demand for dynamic postural control in seniors. In order to do so, a novel experimental protocol involving a stability limit postural task and a secondary attentional task was performed separately and concurrently in various experimental conditions varying the proprioceptive and attentional demands.

3.2—Hypotheses

1) First, we hypothesize that the most impactful age-related differences in the performance of the dynamic postural tasks will be seen under the dual-task condition because of the limited attentional capacity of seniors to concurrently cope with high proprioceptive and cognitive demands

2) Second, we also hypothesize that the impact of removing visual information will be more important in older than in younger participants due to the increasing demand for proprioceptive processing. Also, given that proprioceptive processing also has an attentional demand, the effect of removing vision on postural control of older participants will be accentuated in the dual-task condition.

3) Third, we hypothesize that the performance of older adults in the cognitive attentional task will be most affected when performed concurrently with the postural task in the absence of vision, due to attentional resources being allocated to the prioritization of posture in older adults

CHAPITRE 4—Methodology

4.1—Participants

Twenty-one healthy sedentary older adults (SOA) (mean age = 70.2; range 62-74) and eighteen healthy sedentary young controls (SYC) (mean age = 23.4; range 20-32) participated in this study after providing informed consent on a form approved by the institutional ethics review board of both the Université de Montréal and the institute of the geriatric research centre (Approval number: CER VN 18-19-36). Participants were included if they were classified as sedentary (i.e. performed less than 150 minutes of moderate to vigorous physical activity, according to the CSEP-Questionnaire on physical activity and sedentary behaviour) and had normal or corrected-to-normal vision and auditory hearing. Participants then completed a general health questionnaire disclosing age, sex, and history of disease and were screened for mild cognitive impairments and dementia using the Montreal cognitive assessment form (MOCA), (Nasreddine et al., 2005). Participants were then excluded if they had musculoskeletal, sensory, or neurological deficits that could interfere with the postural task or scored less than 26 / 30 on the MOCA. All participants were evaluated in a single experimental session. Participants were recruited through word of mouth and through the participant bank at the institute of geriatric research centre.

4.2—Stability Limit Postural Task

4.2.1—Experimental set up and procedures

The experimental setup and postural task used in this study are similar to the eyes opened and eyes closed conditions described in a previous paper (Blanchet et al., 2014). At the beginning of each trial, participants stood on a force platform with bare feet and arms crossed on the chest. The standard initial stance position established by McIlroy and Maki (1997) was used. Participants were asked to maintain an upright quiet standing position (60 s). After an auditory signal from the application "MultiTimer" was given, participants were instructed to lean as far as possible in one of four directions (forward, backward, rightward and leftward) without lifting their feet or flexing their hips. Participants were then asked to maintain their maximum leaning position for 10 s, until another auditory signal was given, and subsequently, to return to their initial standing position (30 s).

Prior to the experiment, each subject performed a practice trial to ensure that task instructions were well understood. In the practice trial each subject was instructed to centre their bodies between their two feet and to refer to the position as the initial position in which they would be required to return to post-leaning. Also, anthropometric measurements of the subject's feet (length and width) were assessed and their footprints were traced on the force plate to ensure that the feet position was consistent from trial-to-trial. Importantly, no feedback about their performance was given to the participants during the testing session.

4.2.2—Sensory-attentional conditions

Participants performed five experimental conditions. The order of the five experimental conditions was counterbalanced in the following sequence (Fig. 1).

<table>
<tr><th colspan="5">CONDITION SEQUENCE ORDER</th></tr>
<tr><td colspan="5">A</td></tr>
<tr><td colspan="5">→</td></tr>
<tr><td>SECONDARY ATTENTIONAL TASK (SITTING)</td><td>EO</td><td>EO + 2nd Task</td><td>EC</td><td>EC + 2nd Task</td></tr>
<tr><td colspan="5">←</td></tr>
<tr><td colspan="5">B</td></tr>
</table>

Figure 1 A visual representation of the two varying condition sequence orders used on participants. Where EO designates eyes open; EC designated eyes closed and 2nd Task designates the secondary attentional task. Participants either underwent sequence A (starting with the sitting attentional task and ending with the EC + 2nd Task) or B (starting with the EC + 2nd Task and ending with the sitting attentional task)

First, we assessed postural stability limits in four conditions that varied the proprioceptive and attentional demand during the maximal leaning movements. These conditions were performed separately and simultaneously.

4.2.2.1—Sensory Condition

For the sensory condition, participants performed two of the maximal leaning movements in an eyes open and eyes closed conditions. In the eyes open condition; participants had full vision of the environment at all times. To ensure that the same head position was maintained across trials, participants were asked to stare at a target (2 cm diameter) displayed straight ahead of them (3 m distance). In the eyes closed condition, participants were instructed to keep their eyes closed during data collection, but to open their eyes in between each trial. Participants were encouraged to remember the target's position in order to keep their head in the same position across trials.

4.2.2.2—Attentional Condition

For the attentional condition, participants performed two of the maximal leaning movements with and without the secondary attentional task. The experimental set up for the secondary attentional task consisted of a novel subtraction task in which participants were asked to subtract three (n-3) from a list of sixteen randomized two-digit numbers set at an automatized continuous speed of 2.5 seconds. Participants were asked to reply their answers aloud while either simultaneously.

A) Standing (60 s) and then maximally leaning as far as possible in one of four directions (forward, backward, rightward and leftward) (10 s). Participants were also instructed to continue replying to the following number if they were to become stuck on one of the programmed numbers. The automated sequence of two-digit numbers was manually started after 30 s of quiet static standing for trials where both the postural stability limit task and the attentional task were simultaneously performed. The sequenced numbers were timed to stop once participants returned to the final quiet standing position.

B) Sitting, in the controlled condition, with eyes open. This condition began and ended with the recorded numbers.

Prior to the experiment, each subject was shown a preview of three random digits at the same speed at which they were to respond (every 2.5 seconds) for each trial in which the secondary attentional task would be present. A bank of nine varying sequences of two-digit numbers were created and used for each subject in order to avoid repetition of the same sequence of digits being used throughout the experimental session. Importantly, no feedback about their performance was given to the participants during the testing session.

A complete data set included one maximal leaning movement for each of the four directions for the 4 experimental conditions, for a total of 16 trials. An additional control trial was done sitting for the attentional task.

4.2.3—Kinematic recordings and data analysis

4.2.3.1—Postural stability limit task

Vertical and horizontal ground reaction force data were collected using two force plates (Accugait, AMTI, Inc.), one per foot, at a sample rate of 200 Hz. Data collection and processing were performed using the NETFORCE software (AMTI, Inc.). The center of pressure (COP) displacements during the last **10 s of maximum leaning position** was analyzed to characterize the functional limits of stability. The excursion of the total body COP (i.e., the application point of the total ground-reaction force) was computed from the vertical forces (Henry et al., 2001), both in the anterior-posterior (AP) and medial-lateral (ML) direction.

4.2.3.2—Secondary attentional task

Each trial was recorded on an Apple MacBook Air using the photobooth video application and was later analyzed in order to calculate the performance score of each sixteen-sequenced number sets for each of the experimental conditions that included the attentional task.

4.2.4—Performance indices

4.2.4.1—Postural stability limit task

To compare the performance of sedentary young controls and sedentary older adults, in the different sensory conditions, maximal COP excursion (i.e. limits of stability) and COP root mean square (RMS) were computed for leaning movements in each direction. The total amplitude (cm) of the maximum COP excursions (i.e. limits of stability) along the anterior-posterior (AP, during forward and backward leaning) and medial-lateral (ML, during rightward and leftward leaning) axes was analyzed. The amplitude of the maximum COP excursions were calculated as the difference between the mean steady-state COP position during initial quiet standing and the **maximum** COP excursion reached during maximum leaning in each direction. The summation of these values represents the total maximum COP excursion along the AP and ML axes.

The COP RMS (cm) corresponded to the standard deviation of COP displacement during maximum leaning. The COP RMS was calculated along each direction of the leaning movements (i.e. forward, backward, rightward and leftward leaning).

Participants were asked to maintain an upright quiet standing position (60 s). Each trial was recorded on an Apple MacBook Air using the photobooth video application and was later analyzed to make sure postural instructions were respected.

4.2.4.2—Secondary attentional task

The following formula was used in order to calculate the percent error in the performance of the secondary attentional task;

$$performance\ score\ (\%) = \frac{\#\ of\ total\ correct\ answers}{16}$$

Where the total number of correct answers was analyzed for each trial and then divided by the total possible correct answers (sixteen).

4.2.4.3—Dual-task costs

Dual-task costs (DTC) express the effects of the additional costs imposed in individual-task performance in a dual-task setting. DTCs were expressed according to the formula:

DTC = [(single-task — dual-task)/single-task] x 100

Where the single task consisted of sitting, and the dual-task consisted either of performing the attentional task while leaning with eyes opened (DTCo) or with eyes closed (DTCc) (Li et al., 2018). The dual task costs associated with the performance of the attentional task were calculated.

4.2.5—Statistical analysis

4.2.5.1—Sensory-attentional analysis

To test the effect of the sensory and attentional condition on the postural stability limit and the variability of COP displacements of sedentary young and old participants, we computed a three-factor repeated measure ANOVA (2 groups x 2 sensory conditions x 2 attentional conditions). In the current study, the analysis of the sensory-attentional condition was focused on the anterior and posterior direction exclusively. For all statistical analyses, post-hoc pair-wise comparisons were made using Bonferroni corrections and a two-tailed significant alpha (p) level of 0.05 was used.

4.2.5.2—Attentional performance analysis

A separated stat test for the secondary attentional task was performed to assess whether the performance of the attentional task varied under single and dual task conditions in sedentary young and old participants. We computed a two-factor repeated measure ANOVA (2 group x 3 attentional conditions). In the current study, the analysis of the secondary attentional task was focused on the anterior and posterior direction exclusively. For all statistical analyses, post-hoc pair-wise comparisons were made using Bonferroni corrections and a two-tailed significant alpha (p) level of 0.05 was used.

CHAPITRE 5—Results

5.1—Limits of stability

Fig. 2 represents the mean stability limits (cm) during maximal forward and backward leaning for the four experimental conditions and the two subject's groups. For forward leaning, young adults showed a mean level of stability limit larger than older adults in all sensory and attentional conditions (Fig. 2A, table 1). Furthermore, both groups of participants decreased the magnitude of their stability limits by a similar amount with the removal of vision both under the single and the dual-task conditions. By contrast, for each sensory condition, the mean stability limits of young and old adults remained similar with the addition of the attentional task. Accordingly, the ANOVA showed a significant main effect of group (F (1,37) = 89.455, p < 0.001, n^2p = 0.974) as well as a significant main effect of sensory condition (F (1,37) = 60.251, p < 0.001, n^2p = 0.620). However, no effect of attentional condition was found on the limits of postural stability (F (1,37) = 0.665, p = 0.420, n^2p = 0.018).

Table 1 Limits of stability across experimental conditions

	Older adults				Young adults			
	Anterior		Posterior		Anterior		Posterior	
Condition	Mean (cm)	SD	Mean (cm)	SD	Mean (cm)	SD	Mean (cm)	SD
EO	5.55	± 0.95	3.95	± 1.55	9.36	± 1.26	4.65	± 1.42
EC	4.64	± 1.14	3.30	± 1.45	7.88	± 1.47	3.90	± 1.14
EO + AT	5.45	± 1.41	3.54	± 1.32	9.05	± 1.78	4.46	± 1.63
EC + AT	4.59	± 1.35	3.34	± 1.25	7.89	± 1.37	3.97	± 1.09

Table 1 Presentation of the mean stability limits during maximal forward and backward leaning in the four experimental conditions and two subject groups, where EO is eyes open, EC is eyes closed, EO+AT is eyes open plus attentional task and EC+AT is eyes closed plus attentional task

The average stability limits computed for maximal backward leaning (Fig. 2B), although much smaller in magnitude than for forward leaning, showed similar trends across groups and conditions. The mean postural stability limits of young adults were systemically greater than those of older adults. Furthermore, the stability limits of both subject's groups decreased from the eyes open to the eyes closed conditions and were unaffected by the addition of the secondary attentional task. In contrast to forward leaning, when the ANOVA was applied on the stability limits for backward leaning, the between group difference did not reach the significance level ($F(1,37) = 3.362$, $p = 0.075$, $n^2p = 0.083$). However, there was a significant main effect of sensory condition ($F(1,37) = 15.873$, $p < 0.001$, $n^2p = 0.300$), while no effect of attentional condition was found on the stability limits obtained for backward leaning ($F(1,37) = 0.994$, $p = 0.325$, $n^2p = 0.026$).

Figure 2: The anterior and posterior limits of stability in sedentary young and old adults

A.

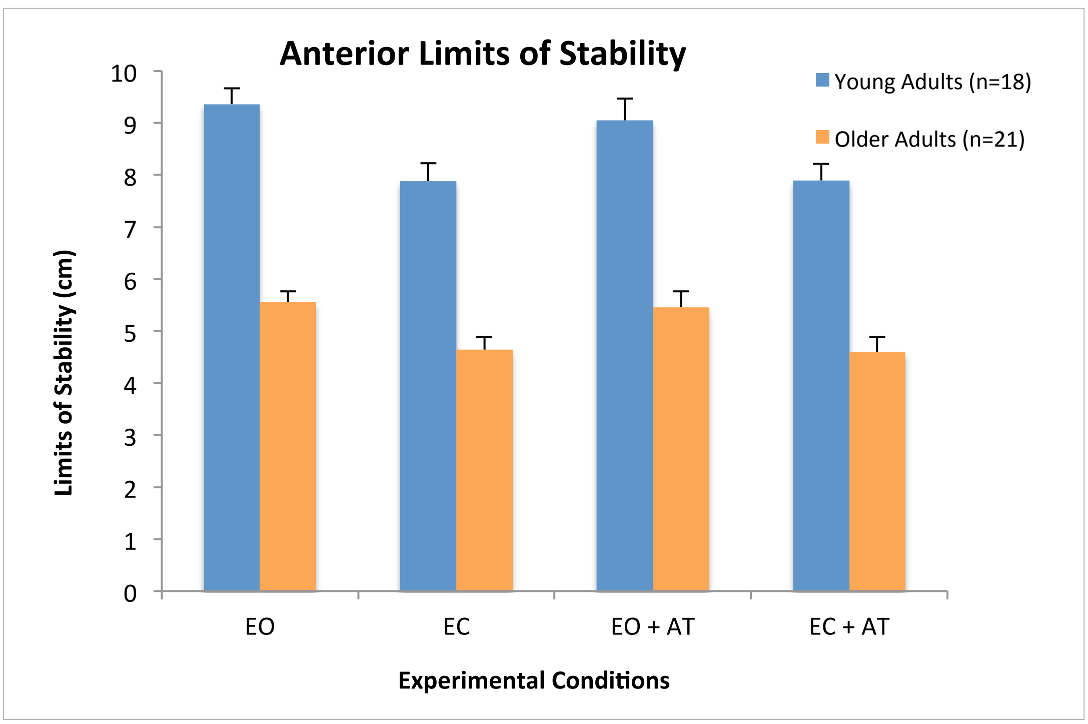

Figure 3A Presentation of the mean stability limits during maximal forward leaning in the four experimental conditions and two subject groups, where EO is eyes open, EC is eyes closed, EO+AT is eyes open plus attentional task and EC+AT is eyes closed plus attentional task

B.

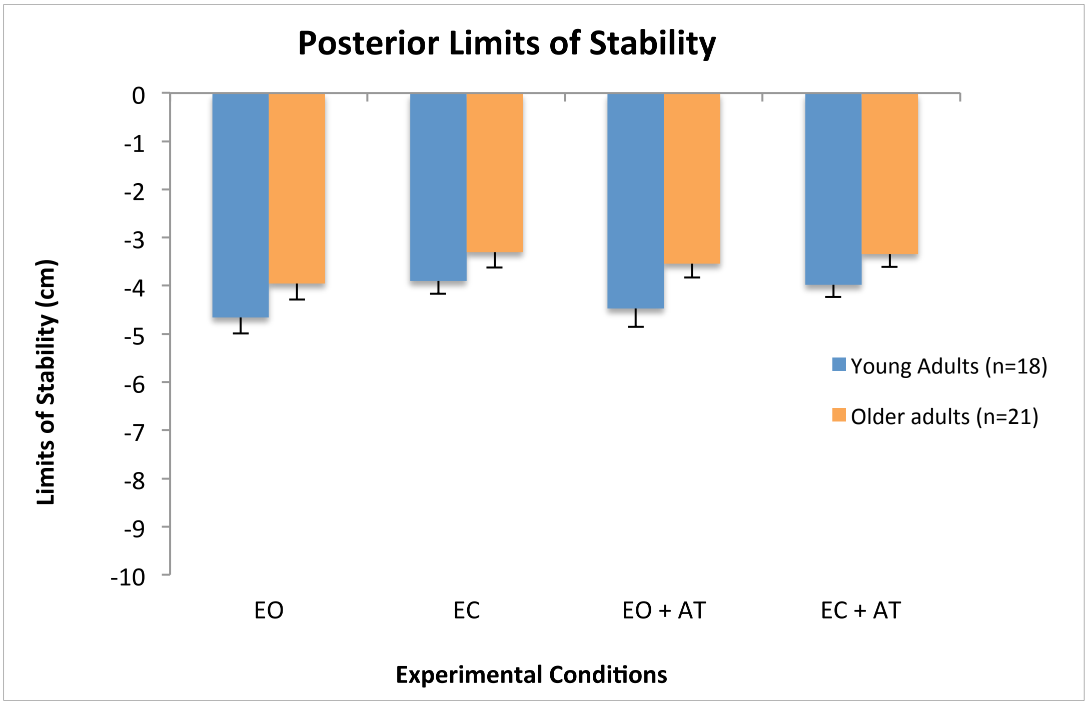

Figure 4B Presentation of the mean stability limits during maximal backward leaning in the four experimental conditions and two subject groups, where EO is eyes open, EC is eyes closed, EO+AT is eyes open plus attentional task and EC+AT is eyes closed plus attentional task

5.2—RMS of stability limits

Fig. 3AB represents the mean root mean square (RMS) during maximal forward and backward leaning for the two subject's groups across all experimental conditions (table 2). For forward leaning, young and old adults both showed a systematic increase in RMS values from the eyes open to the eyes closed conditions. However, for each sensory condition, they exhibited opposite trends from the single to the dual task conditions. Young adults increased their average RMS when concurrently performing the attentional task, while older adults decreased their mean RMS with the addition of the attentional task. Consistent with these observations, the ANOVA did not show a significant main effect of group on RMS values for maximal forward leaning (F (1,37) = 0.177, p = 0.676, n^2p = 0.005), but, there was both a significant main effect of the sensory condition (F (1,37) = 20.630, p < 0.001, n^2p = 0.358), as well as a significant group by attentional condition interaction (F (1,37) = 4.538, p = 0.040, n^2p = 0.109).

However, post hoc pair-wise comparisons did not indicate a significant difference between the two cognitive conditions for both older (p = 0. 255) and young (p = 0.059) subjects.

Table 2 Root mean square across experimental conditions

	Older adults				Young adults			
	Anterior		Posterior		Anterior		Posterior	
Condition	Mean (cm)	SD	Mean (cm)	SD	Mean (cm)	SD	Mean (cm)	SD
EO	0.74	± 0.28	0.72	± 0.32	0.63	± 0.32	0.53	± 0.17
EC	0.89	± 0.26	0.95	± 0.41	0.80	± 0.22	0.70	± 0.19
EO + AT	0.68	± 0.22	0.77	± 0.22	0.76	± 0.34	0.57	± 0.18
EC + AT	0.84	± 0.21	0.94	± 0.32	0.86	± 0.22	0.76	± 0.15

Table 2 Presentation of the root mean square during maximal forward and backwards leaning in the four experimental conditions and two subject groups, where EO is eyes open, EC is eyes closed, EO+AT is eyes open plus attentional task and EC+AT is eyes closed plus attentional task

In contrast to forward leaning, the mean RMS for maximal backward leaning of older adults was systemically larger than those of young adults. Both groups of participants displayed similar tendencies across conditions (Fig. 3B). Young and old adults systematically increased their mean RMS with the removal of vision under the single and dual task conditions. Furthermore, the addition of the attentional task did not cause substantial changes to the mean RMS of either group while leaning backward. As a result, the ANOVA indicated significant main effects of group (F (1,37) = 14.439, P = 0.001, n^2p = 0.281) and sensory condition (F (1,37) = 23.622, P < 0.001, n^2p = 0.390), but no effect of attentional condition on RMS for backward leaning (F (1,37) = 0.827, P = 0.369, n^2p = 0.022).

Figure 5: The anterior and posterior RMS in sedentary young and old adults

A.

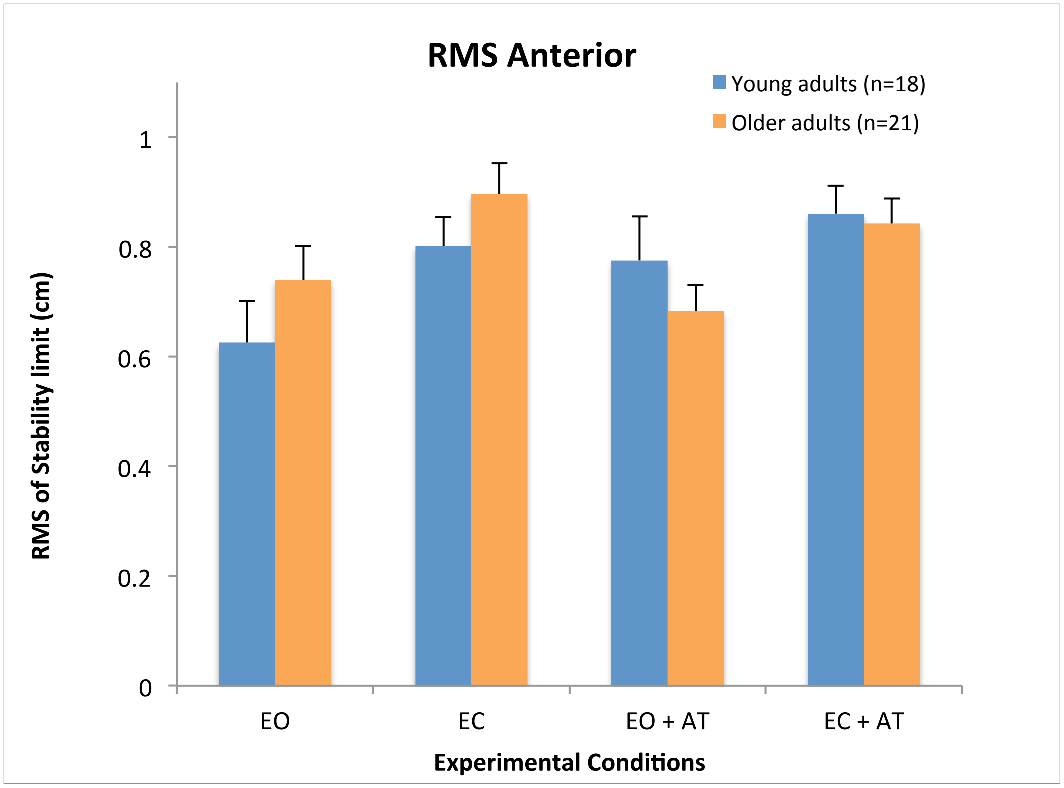

Figure 3A Presentation of the root mean square (RMS) during maximal forward leaning in the four experimental conditions and two subject groups, where EO is eyes open, EC is eyes closed, EO+AT is eyes open plus attentional task and EC+AT is eyes closed plus attentional task

B.

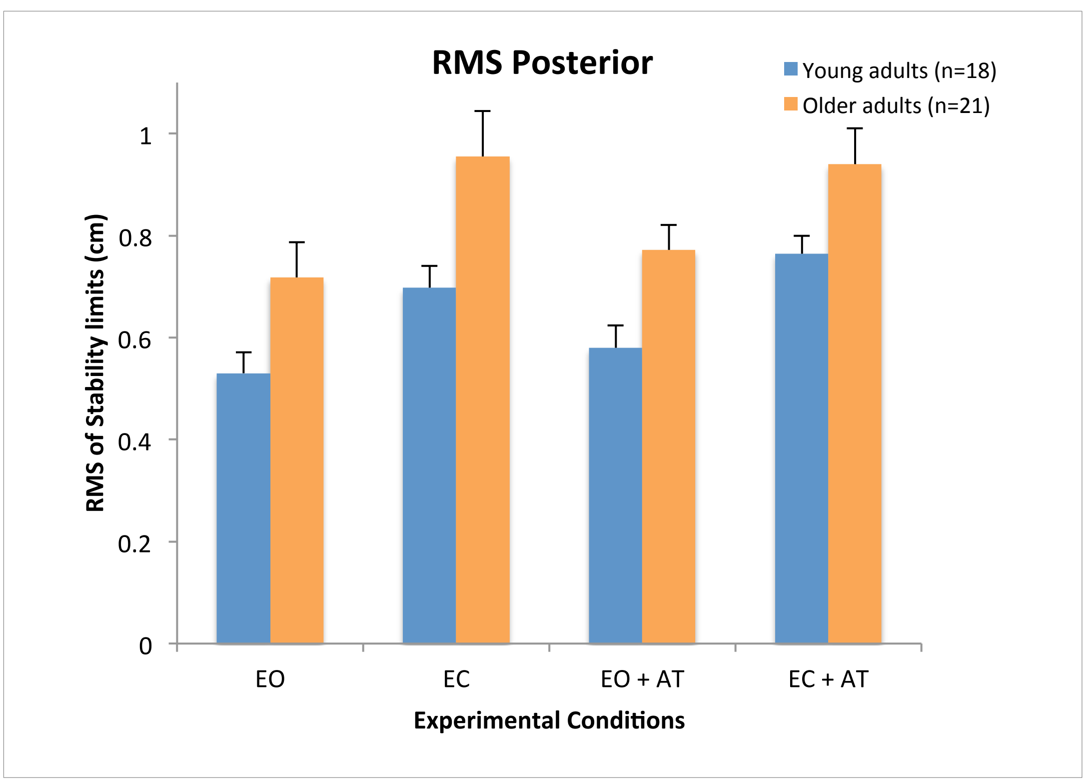

Figure 3B Presentation of the root mean square (RMS) during maximal backward leaning in the four experimental conditions and two subject groups, where EO is eyes open, EC is eyes closed, EO+AT is eyes open plus attentional task and EC+AT is eyes closed plus attentional task

5.3—Attentional Task

Fig. 4A,B represents the average success rate in the attentional subtraction task for both subject groups during sitting and during maximal leaning with eyes open and eyes closed (table 3). For forward leaning, young adults made, on average, fewer errors (i.e. higher percentages) than older adults in all conditions (Fig. 4A). Furthermore, young adults only slightly reduced their average success rate when concurrently performing the stability limit task. Conversely, older adults exhibited a marked and progressive decrease in their mean success rate across conditions, showing their lowest score when concurrently performing the attentional and the postural stability tasks in absence of vision. As a result, the between group differences increased systematically from the sitting to the postural eyes closed condition. Accordingly, the ANOVA applied on the success rate revealed a significant main effect of group ($F(1,37) = 16.154$, $p < 0.001$, $n^2p = 0.304$), a significant effect of attentional condition ($F(1,37) = 25.465$ $p < 0.001$, $n^2p = 0.408$) as well as a significant group by attentional condition interaction ($F(1,37) = 4.821$, $p = 0.034$, $n^2p = 0.233$). Post hoc tests revealed that young and old participants significantly differed in all three attentional conditions, including sitting ($p = 0.033$, $d = 0.724$), EO2 ($p = 0.008$, $d = 0.925$), and EC2 ($p < 0.001$, $d = 1.353$) . Therefore, the group by attentional condition interaction was explained by the differential impact of the attentional conditions in young and older participants.

Table 3 Performance score across experimental conditions

	Older adults				Young adults			
	Anterior		Posterior		Anterior		Posterior	
Condition	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD	Mean (%)	SD
Sitting	0.94	± 0.06	0.93	± 0.07	0.98	± 0.04	0.98	± 0.04
EO + AT	0.85	± 0.13	0.86	± 0.12	0.94	± 0.07	0.95	± 0.08
EC + AT	0.79	± 0.15	0.85	± 0.13	0.95	± 0.13	0.95	± 0.07

Table 3 Presentation of the average success rate in the attentional subtraction task for both subject groups during sitting and during forward and backward maximal leaning with eyes open and eyes closed, where EO2 is eyes open and EC2 is eyes closed

Similar trends were observed when the success rate during the sitting was compared to the limits of stability during backward leaning (fig. 4B). Young adults showed systematically higher success rate then older adults. Further, the performance score of young adults remained relatively similar across attentional conditions, whereas those of older adults were markedly reduced when both the attentional and postural tasks were performed simultaneously. The ANOVA supported these observations. There were main effects of both group ($F(1,37) = 12.551$ $p = 0.001$, $n^2p = 0.253$) and attentional condition ($F(1,37) = 14.808$, $p < 0.001$, $n^2p = 0.286$). However, in contrast to forward leaning, the group by attentional condition was insignificant ($F(1,37) = 2.867$, $p = 0.099$, $n^2p = 0.072$).

Figure 6: Secondary attentional task anterior and posterior performance score of sedentary young and old adults

A.

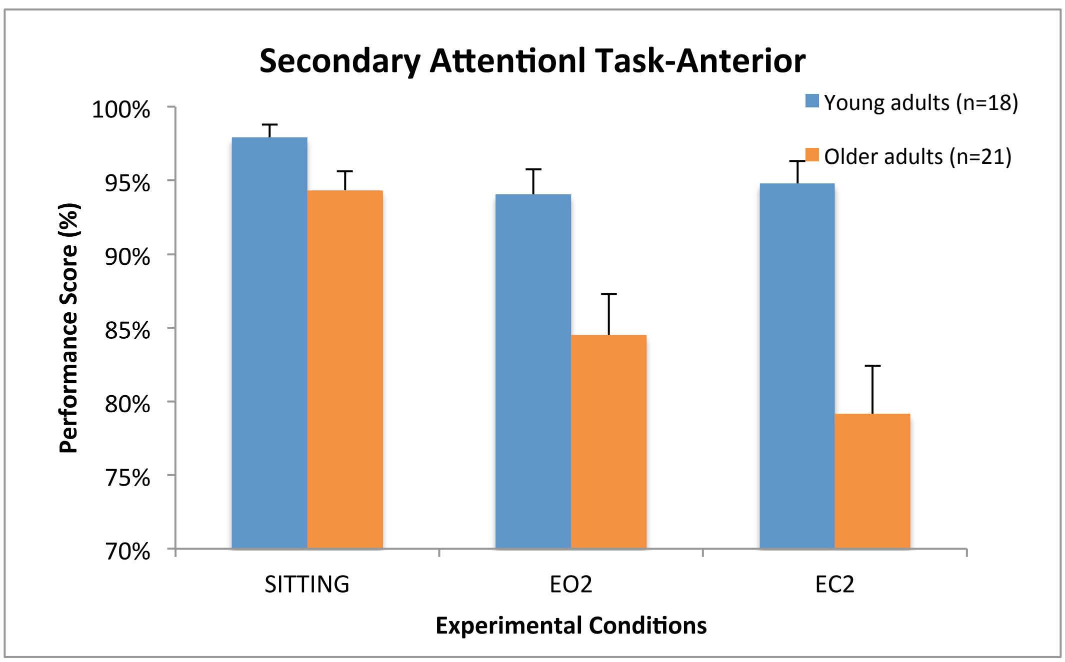

Figure 4A Presentation of the average success rate in the attentional subtraction task for both subject groups during sitting and during forward maximal leaning with eyes open and eyes closed, where EO2 is eyes open and EC2 is eyes closed

B.

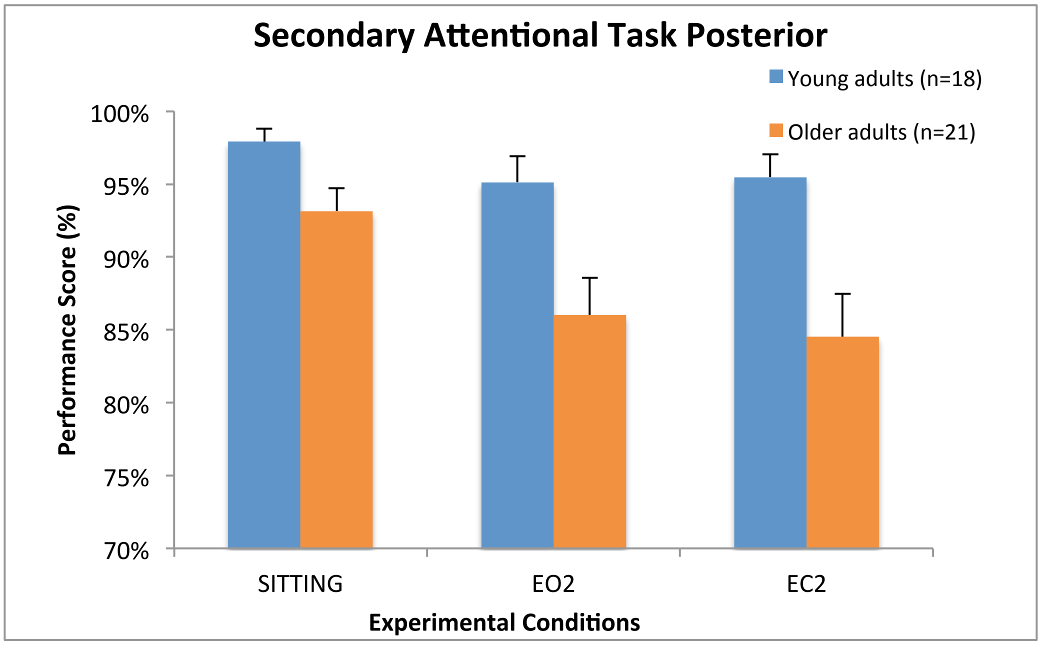

Figure 4B Presentation of the average success rate in the attentional subtraction task for both subject groups during sitting and during backward maximal leaning with eyes open and eyes closed, where EO2 is eyes open and EC2 is eyes closed

5.3.1—Dual Task Costs

Older adults displayed a higher average dual task cost in the anterior direction in both the eyes open (10.560 $\pm$ 10.912%) and eyes closed (16.124 $\pm$ 14.634%) conditions compared to younger adults (eyes open = 3.988 $\pm$ 6.029%, eyes closed = 3.198 $\pm$ 5.467%,). Accordingly, the ANOVA applied on the dual task costs revealed a significant group effect for the anterior direction (F (1,37) = 14.113, p = 0.001, n^2p = 0.276). However, there was no significant main effect of the sensory condition (F (1,37) = 1.380, p = 0.248, n^2p = 0.036), as well as no group by sensory condition interaction (F (1,37) = 2.446, p = 0.126, n^2p = 0.062).

Older adults displayed a higher average dual task cost in the posterior direction in both the eyes open (7.767 $\pm$ 9.297%) and eyes closed (9.283 $\pm$ 12.988%) conditions compared to younger adults (eyes open = 2.798 $\pm$ 7.544%, eyes closed = 2.454 $\pm$ 6.234%). Accordingly, the ANOVA applied on the dual task costs revealed a significant group effect for the posterior direction (F (1,37) = 6.156, p = 0.018, n^2p = 0.143).

However, there was no significant main effect of the sensory condition ($F(1,37) = 0.092$, $p = 0.763$, $n^2p = 0.002$), as well as no group by sensory condition interaction ($F(1,37) = 0.232$, $p = 0.633$, $n^2p = 0.006$).

CHAPITRE 6—Discussion

Summary of main findings

This is the first study, to our knowledge, that has investigated the interaction between proprioceptive and attentional demands of dynamic postural control in older adults. First, older adults have smaller forward stability limits compared to young adults across all sensory attentional conditions. Second, the stability limits of both groups decreased when vision was removed, but were unaffected by the addition of the attentional task. Third, when maintaining their maximal stability limits, young and older participants increased their COP variability with the removal of vision for both leaning directions. Interestingly, when concurrently performing the attentional task and leaning forward, young adults tended to increase their COP variability but older adults decreased their average COP variability. Fourth, young adults showed an overall higher performance score than older adults in the secondary attentional task. However, importantly, there was only a slight difference between groups when they performed the attentional task in the single condition, i.e. while sitting. In striking contrast, older adults markedly degraded their performance in the attentional task when concurrently performing the postural task. Hence, this performance reduction was more pronounced in the eyes closed condition. The implication of these findings is discussed in the following sections.

6.1—Effects of Aging on Dynamic Postural Stability Limits

Over the last decade, a plethora of studies investigated postural control in aging (see Rath et al., 2017 for review). Many studies reported reduced static postural stability with increasing age even when there was no somatosensory or cognitive challenge (Benjuya et al., 2004; Huxhold et al., 2006; Blaszczyk et al., 2016; Degani et al., 2017). Despite such, a number of other studies did not find any age-related decline in quiet standing (Schieppati et al., 1994; Doumas et al., 2008; Simoneau et al., 2008). These divergent findings in the literature may be explained by two non-exclusive hypotheses. First, in the healthy older adults we studied, the control mechanisms involved in static postural control are preserved. Second, older adults are able to use compensatory adjustments in order to combat age-related declines of their sensory, neural and motor functions when performing a postural task in static conditions (Benjuya et al., 2004; Simoneau et al., 2008; Kanekar et al., 2014).

Although static postural control has been thoroughly examined in older adults, far fewer studies have investigated the impact of aging on dynamic postural control (Doumas et al., 2009; Huang et al., 2015; Remaud et al., 2016). In contrast to studies assessing quiet standing, almost all reports involving a dynamic condition observed a decrease in the postural performance of older adults compared to their younger counterparts (Doumas et al., 2008; Ko et al., 2015; Kasahara et al., 2015). Of particular interest, among the five studies assessing the limits of stability by measuring the maximal inclined posture, four indicated reduced antero-posterior limits of stability in older adults (Schieppati et al., 1994; Huang et al., 2014; Ko et al., 2015; Kasahara et al., 2015). Our results of significantly smaller anterior stability limits in old compared to young adults across all sensory-attentional conditions are consistent with these previous findings.

Several aspects related to the motoric characteristics of postural control might explain, in part, the impaired postural performance of older adults in the current study. First, diminished muscle strength at the ankle joint may have reduced both the magnitude of stability limits as well as the ability of older participants to maintain their maximal leaning posture. Decreases in the maximal strength of ankle plantar and dorsal flexor muscles is a common manifestation of age-related declines in neuromuscular function and have been found to markedly aggravate postural instability in seniors (Cattagni et al., 2014). Notably, plantar flexor muscle strength was found to play a key role in postural stability during reaching tasks, as in situations that challenge anterior stability limits like the forward leaning in our stability limit task (Melzer et al., 2009). The capacity to control one's balance while leaning forward is critical to daily living. Because it is undeniable, that such postural skill requires force, we believe that decreases in ankle muscle strength in older adults may have contributed to the observed reduced stability limits across all experimental conditions. Future studies should assess ankle strength to dissociate the specific effect of this factor from other sensorimotor declines arising during the aging process and to better predicts falls.

Second, the reduced forward limits of postural stability of older adults in the current study may also reflect, in part, a general inability to properly coordinate muscular activity and torques at the ankle joint (Donath et al., 2015). Age-related alterations in the neural control of muscles have been linked to both a lower rate of force development and a marked reduction in the ability to coordinate muscles effectively (Darling et al., 1989; Morgan et al., 1994). Hence, degenerative changes to the neuromuscular system have been suggested to limit the flexibility with which muscle coordination patterns at the ankle are formulated and executed (Izquierdo et al., 1999; Barry et al., 2005). Therefore, it is plausible that such age-related muscle coordination deficits exacerbated the difficulties of older adults in producing stability limits comparable to younger participants in the current study.

Third, the reduced stability limits of the older participants might also be linked to suboptimal performance in anticipatory postural adjustments (APA's) (Kanekar et al., 2014). Postural leaning is centrally mediated through anticipatory postural adjustments (APA's), which allow postural adjustments in order to maintain balance during voluntary movements (Carvalho et al. 2010; Santos et al., 2010). Previous studies have demonstrated that older adults exhibit delayed and smaller APAs and subsequently, larger compensatory muscle activities to restore balance when exposed to external perturbations (Kanekar et al., 2014). Future detailed analyses of the current data set will assess if anticipatory postural adjustments of older adults are reduced and/or delayed while performing this voluntary unperturbed leaning task and whether such a reduction can linked to the magnitude of stability limits. These anticipatory postural adjustments can be assessed by measuring the backwards shifts before the actual leaning movement.

Moreover, the finding that the limits of stability of older adults was reduced compared to young adults even when vision was available and no attentional demand was added provides further evidence that dynamic postural control is impaired in aged participants. The stability limit task used in this study is therefore a sensitive measure for evaluating postural mechanisms during the aging process. In line with our finding, Kasahara and colleagues (2015) found that when older adults were asked to shift their centers of pressure (COPs) as far possible forward while standing on a force platform with no sensory attentional task, they performed significantly smaller distances compared to younger participants. Age-related decreases in the quality of proprioceptive sensitivity (Shaffer and Harrison 2007), and an increase in the attentional demand for postural control have both been established as mediators in fall risk among older adults (Cattagni et al., 2014; Woollacott and Shumway-Cook, 2002). Consequently, the reduced anterior limits of stability in older adults observed in this study may also be a result of the sensory attentional challenges imposed on older adults across experimental conditions. This hypothesis will be discussed in a later section.

A single recent study reported a preservation of the limits of stability in elderly adults (Degani et al., 2017). They attributed their divergent finding to the fact that elderly adults in their study were at the early stage of the aging process (65-74, mean=68.8 years (SD=3.2)). It is noteworthy that in all previous studies investigating postural stability limits in aging, the level of physical activity was left uncontrolled. In the current study, older adults were also at the relatively early stage of aging (62-77, mean=70.2; SD=3.9), but only sedentary participants were included. Previous research indicates that the level of physical activity effects postural stability in aged participants

(Petrella et al., 2017; Maitre et al., 2013). Therefore, it is possible that the low physical activity level of older participants tested in the current study also partially explain our finding of significantly smaller anterior postural stability limits.

In contrast to the forward direction, the backward limits of stability were not significantly different from young adults. This divergent finding might be due to a floor effect on maximum backward inclination common to both older and younger adults due to the biomechanical constraints of backwards leaning (Horak et al., 1989; Mancini et al., 2014). The backward direction is the most critical in terms of maximal displacement, due to its diminished area of support (Schieppati et al., 1994). However, it is worth mentioning that the similar backward stability limits between age groups was coupled with a significantly greater level of COP variability in older adults. This indicates that postural stability at the backward maximal limit was not entirely unaffected by aging.

Finally, another critical factor that may have had an impact on the anterior and posterior postural stability limits is fear of falling (FOF). It is well known that the potential effects of falls include fear of future falls. The risk of falls is linked to several aspects of the physical capacity of older adults such as decreasing strength, balance and coordination difficulties, sensory impairments as well as low levels of physical activity (Skelton, 2001). Since only sedentary older adults were tested in the present study, FOF may have been a contributor to our findings. However, one might suggest that if FOF had played a substantial role in the diminished stability limits of older adults, it might have more strongly impacted postural control in the no vision condition or when the cognitive task was added. The observation of a similar reduction in stability limits when vision was removed among groups as well as the finding that the addition of the secondary attentional task did not altered the magnitude of stability limits make this possibility unlikely. In support to this assumption, one previous study reported no interference effect between FOF and postural control in the context of a dual-task paradigm in older adults (Reelick et al, 2009). Furthermore, no participants spontaneously expressed a fear of falling while performing our leaning task. For these reasons, we believe that FOF did not largely explain our results. However, since we cannot entirely rule out the contribution of FOF to our findings, future studies using a dynamic postural task may benefit from including an objective measure of FOF. With that said, physical limitation is related to the size of the base of support, which is directly related to feet size. It is therefore noteworthy to mention that the foot length of participants in this study were measured and compared using a t-test, in which no significant group difference was found.

6.2—Effect Of Proprioceptive And Attentional Demands On Postural Stability Of Aged Participants

The main objective of this study was to exploit the dual-task paradigm to assess the impact of proprioceptive and attentional demands on the postural control of aged participants. Firstly, an important finding related to this issue is the observation that old and young adults showed a similar reduction in their postural stability limits when vision was removed, i.e., when postural control relied more heavily on proprioceptive sensation. This result was unexpected given that proprioception is a primary source of sensory information for perceiving the limits of postural stability (Horak et al., 1989; Globe et al., 2009; Henry and Baudry, 2019) and that the integrity of the proprioceptive system declines with increasing age (Lord et al., 1991; Globe et al., 2009, Henry & Baudry, 2019). Furthermore, a number of studies have reported a link between age-related alterations in proprioceptive sensitivity and postural stability (Woollacott et al., 1986; Hay et al., 1996;, Speers et al., 2002; Doumas et al., 2009; Degani et al., 2017).

It is well accepted that information carried by each sensory modality is weighted according to both the task and the functional state of the modality (Martin et al., 1991; Henry and Baudry, 2019). According to this view, the most reliable sensory inputs contribute more strongly to postural control, while the less reliable inputs are weakened

(Doumas et al., 2008). Along this line, we predicted that aged participants, in whom proprioceptive sensations were altered, would decrease their reliance on proprioceptive input, thereby increasing their dependence on visual information as a compensatory mechanism (Haibach et al., 2009; Eikema et al., 2012). A number of studies demonstrated that altered proprioception makes older adults more dependant on visual information to control posture (Franz et al., 2015; Jeka et al., 2010; Kabbaligere et al., 2017), However, we know very little on the direct association between increased reliance on vision and proprioceptive sensitivity (Henry and Baudry, 2019). It is noteworthy that one study involving a large sample of older adults (n=95) reported that individuals with poor proprioception showed larger sway in the anterior-posterior direction, regardless of whether the task was performed with or without vision (Lord et al. 1991). Our results are consistent with these findings. However, given that proprioceptive sensitivity was not assessed in the current study. i.e. in a proprioceptive task having very little or no motoric component, it is not possible to dissociate whether the large decrease in the magnitude of stability limits of older adults in both the eyes open and eyes closed conditions reflect proprioceptive impairments not compensated by vision or other factors related to the deterioration of the neuromuscular system due to age.

Another factor that might explain, in part, our findings is the age of the participants. A myriad of studies have indicated that postural control performance progressively declines with advancing age (Huxhold et al., 2006; Prado et al., 2007 Van Impe et al., 2013). Hence, such declines in postural stability have been frequently linked to age-related changes in sensory processing and integration, particularly in processing proprioception (Globe et al., 2011; 2012). As mentioned above, a recent study by Degani and colleagues (2017) reported preserved functional limits of stability in early stages of aging. It is noteworthy that the older participants recruited in this study had a very similar age range to those of Degani and colleagues (2017). However, one critical difference between the studies was that our study controlled for physical activity level.

All participants in the current study were classified as sedentary according to the Physical Activity and Sedentary Behaviour Questionnaire (see ANNEXE 1). Of relevance, Anson and colleagues (2017) recently examined the relationship between postural sway and multimodal sensory processing in aging. They concluded that the proprioceptive function was the best predictor of sway area, whereas age was not a reliable predictor of postural stability. Given that proprioceptive acuity has been shown to be superior in seniors having an active lifestyle (Wright et al., 2011; Adamo et al., 2009) we speculate that older sedentary participants tested in the current study have poorer proprioception compared to both active seniors of similar age as well as young adults. In this line, reduced proprioception likely contributed to their overall smaller limits of stability relative to young adults. It is worth mentioning that anterior studies showing a difference between young and older adults in the no vision condition did not control for the physical activity level (Teasdale et al., 1993; Maylor and Wing, 1996). It is thus plausible that young adults tested in these previous studies were more active than older adults, which would have increased the probability of finding a significant difference between age groups.

Another reason that might explain the observed similar decrease in stability limits of older adults compared to young adults when vision was removed is the possibility that older adults compensated for their greater difficulties in the eyes closed conditions by directing more attentional resources to postural control. Such a strategy would decrease the amount of proprioceptively-based automatic control of posture (Heuninckx et al., 2005). Previous studies have shown that alterations in proprioceptive sensations reduce the efficacy of automatic processing, thereby increasing the higher-level controlled processing and the cognitive loads (Goble, 2009, Henry and Baudry, 2019). If this hypothesis is correct, then further increasing the attentional demand of postural control by adding a secondary cognitive task may severely reduce the stability limits of older adults, especially in absence of vision, where the proprioceptive demand is higher. In contrast, our results revealed that simultaneously performing the attentional task did not alter the limits of stability of both young and old adults. This result is not in accordance with numerous studies reporting degraded postural stability in older adults when a cognitive task that consumed available attentional resources was added (Shumway-Cook et al., 1997; Melzer et al., 2001; Redfern et al., 2002).

The observation that aged participants were able to maintain similar limits of stability while performing the secondary attentional task does not necessarily contradict the hypothesis that greater attentional resources were mobilized when performing the postural task. Indeed, further analyses of the postural performance across the sensory-attentional conditions revealed that in contrast to young adults, who increased their average variability level, aged participants tended to decrease the variability of their COP displacements when maintaining their maximal limits of stability and performing the attentional task. This trend in the variability may reflect the use of a stiffening strategy (Benjuya et al., 2004; Ortega and Farleym2015). Accordingly, older adults may have co-activated the muscles surrounding the ankle joint to maximise stability (Baudry and Duchateau, 2012; Benjuya et al., 2004; Donath et al., 2015). Several studies have reported that older participants maintain upright standing with a greater co-activation level between the plantar flexors and dorsiflexors of the ankle, particularly in challenging postural or sensory conditions (Baudry and Duchateau, 2012; Benjuya et al., 2004; Donath et al., 2015). Of relevance, it was suggested that this co-activation strategy partly reflects a compensatory mechanism of age-related alterations in leg proprioception (Manchester et al., 1989; Nagai et al., 2011). In this perspective, the use of a stiffening strategy may allow older adults to bypass the production of fine proprioceptively-based automatic on-line postural adjustments to maintain postural stability. Hence, such a strategy would allow the allocation of cognitive resources to the challenging concurrent task (Henry and Baudry, 2019).

The possible use of this co-activation strategy to freeze the ankle joint to allow the attentional resources to be placed on the cognitive task is not compatible with several recent studies investigating the impact of a cognitive task on quiet standing in healthy and active older individuals (McNevin et al., 2013; Richer et al., 2017;Richer et al., 2019). A number of studies have demonstrated that adding a secondary attentional task leads to improvements in postural stability without negatively impacting the performance of the cognitive task. According to these authors, as participants focused on the secondary task, their attention shifted from the control of posture towards that of the secondary task, permitting the control of postural stability to recover a more automatic and efficient control. In other words, removing attention from the control of posture, promote automaticity, i.e. allows more efficient automatic processes rather than the use of a compensatory ankle stiffening strategy. Although co-activation of ankle muscles was not assessed in the current study, the observed reduction in COP variability combined with the reduced stability limits of old adults in all conditions, suggest that sedentary aged subject used a stiffening strategy when in the dual-task situations rather than improving and using an efficient automatic processing strategy.

Furthermore, it appears that this compensation strategy was not sufficient to disengage attentional resources from the control of posture. If ankle stiffening would have substantially removed attention from the control of posture, then one would expect that older adults should have performed equally well in the cognitive-attentional task across all conditions, i.e., while sitting and when concurrently performing the postural task. In striking contrast, older adults markedly decreased their performance score in the cognitive task while simultaneously performing the postural task and this trend was exacerbated in the eyes closed condition, when the demand for proprioceptive processing was higher. This finding suggests that, in older participants, attentional resources were shared between postural control and the cognitive task, which interfered with their ability to successfully accomplish the cognitive subtraction task. Also, the observed average decrease in the performance in the cognitive task in the eyes closed condition when participants relied more on proprioception is compatible with recent evidence indicating that processing proprioception per se mobilizes attentional resources (Yasuda et al., 2014).

Furthermore, other studies have demonstrated that when older adults are in challenging postural conditions, such as when the quality of proprioceptive inputs is reduced through platform-based sway, participants sacrificed performance on the cognitive task in favour of maintaining postural stability (e.g Doumas, 2008). This finding suggested that older adults perform postural task with less automaticity than younger adults when placed in compromised proprioceptive feedback conditions. In a similar manner, the older participants in the present study appeared to have prioritized postural control over cognitive performance to counteract the internal perturbation cause by the voluntary learning movement in order to avoid a potential fall.

6.3—Study Limits

In the present study, we exploited the dual-task paradigm to assess the impact of proprioceptive and attentional demands on the postural control of seniors. The findings suggested that our dynamic postural stability limit task is a sensitive predictor of impairments and disability in aging. Furthermore, the results provided evidence for an interaction between proprioception and attention in the postural control of seniors. However, some limitations of the present study may have had an impact on the results.

First, the attentional task used in this study may not have been challenging enough to produce a deterioration of the postural task as well as a larger degradation of the performance scores in the cognitive task. The attentional subtraction task used in the current study involved a set of sixteen two-digit (30s) while the duration of each trials lasted 110 sec. Because of this limited number of possible combinations, certain numbers reappeared throughout the trials, causing the task to be less difficult. A number of studies indicated that the level of difficulty of the cognitive task influences postural control in dual task paradigms (Boisgontier et al., 2013). Hence, a recent study demonstrated that the use of a continuous cognitive task could have a greater impact on the postural control of older adults compared to a discrete cognitive task (Benjuya et al., 2004). In this perspective, future studies should use a larger set of numbers in order to augment the cognitive load. This would increase the dual-task difficulty as well as force the continuous use of attentional resources.

Second, future studies should investigate larger groups of older adults as our current results were weakened by a rather small sample size and high variability. This would increase statistical power as well as allow the formation of different age-subgroups to assess how the proprioceptive and attentional demands influence postural control across the lifespan.

Finally, another factor that could have impacted the performance of all participants in the experimental protocol was fatigue (Papa et al., 2015). Participants performed sixteen ninety-second trials in which they were instructed to lean as far as possible as well as maintain their maximal inclined posture for ten seconds. Furthermore, in the dual-task conditions, the cognitive attentional task was performed during 45sec. Despite the fact that breaks were imposed in-between trials to limit the effect of fatigue, the muscles surrounding the ankle were highly solicited during a testing session, which might have impacted the performance of all participants. Some studies reported that muscle fatigue increases centre of pressure sway area and velocities during quiet standing (Nam et al., 2013; Parreira et al., 2013). Therefore, one might suggest that muscle fatigue may augment age-related changes in sensory and motor functions, and also increase the attentional demand associated with dynamic postural control. Although, a recent study by Remaud and colleagues (2016) indicated that dynamic postural control is only minimally affect by local muscle fatigue in both young and older adults, this might not be the case in advancing age, especially in less active and physically health seniors. Therefore, future studies should use Borg's rate of perceived exertion scale in order to quantify the fatigue experienced from the postural task.

6.4—Future Studies

Future studies will first be aimed at investigating the interaction between attention and proprioception in seniors when there are no postural control requirements. Recent work indicated that allocation of attentional resources toward a difficult cognitive task compromised ankle proprioceptive performance in young adults (Yasuda et al., 2014). This finding is important, as ankle proprioception is crucial for postural stability in most activities of daily life. However, whether increased attentional demand alters the ankle proprioceptive sensitivity of seniors has never been investigated. Testing proprioceptive skills of seniors when there is no postural control demand is essential to dissociate between disturbances in proprioception from potential deficits in visual processing, in visuo-proprioceptive integration or in the motor component of postural control that may occur in aging. Furthermore understanding the interaction between attention and proprioception is of paramount importance as alterations in proprioceptive processing potentially reduce the efficacy of automatic processing, resulting in an increase in the controlled processing and the cognitive load associated with postural control (Henry and Baudry, 2019).

Another future line of research will test the effects of an intervention program aimed at improving proprioception for postural control in complex everyday situations involving varying levels of attentional demand. Regular physical exercise has been suggested to tapper the decline of proprioception in older adults (Adamo et al., 2009; Ribeiro and Oliveira, 2010). By preserving proprioception and reducing the need to allocate attentional resources through improved automatic processing, proprioceptive training might be useful for fall prevention programs. Also importantly, as cardiovascular training has been found to improve executive functions in the aging population (Bherer et al., 2015), an interesting question is whether such training would improve attention and proprioception, thereby liberating attentional resources from postural control, increasing postural stability and ultimately reducing fall risk.

6.5—Future Analysis

Future analyses of the current data set will first look at the limits of stability in the medial-lateral (ML) plane. Previous studies have found that cognitive tasks increased the difficulty of the dynamic postural task, particularly when performed in the ML direction (Remaud et al., 2016). Therefore, understanding the attentional demands required for lateral compared to anterior-posterior movements with age is of interest for successful daily functioning.

Additionally, we plan to assess how other key dependant variables are influenced by the sensory and attentional conditions of this study. Such variables include the velocity of COP, and the ellipse area. These variables will be computed for the quiet standing phase preceding the learning movement as well as for the maintenance of the maximal limits of stability. This will provide information on how these two static phases of varying difficulties impact the postural control strategies used by young and older participants. Finally, the postural and attentional performance during these static phases will be compared with the performance during the dynamic phase, i.e. the learning movement to assess whether sensory and attentional challenges during dynamic postural control is more greatly affect by the aging process.

Conclusion

To conclude, this is the first study to our knowledge, that has investigated the interaction between the proprioceptive and attentional demand of dynamic postural control in older adults. Our findings demonstrate that overall older adults produce smaller stability limits when compared to younger adults across varying sensory-attentional conditions. Furthermore, it appears that older adults use various compensation strategies in order to disengage attentional resources from the control of posture when challenged with a cognitive task. This finding supports previous studies that have suggested older adults use a "posture first" or prioritization strategy in order to combat the risk of sustaining a fall. Our findings suggest that older participants attempt to share their attentional resources between postural control and the cognitive task, which results in a decrease performance score in the attentional task. Importantly, the older adults displayed a marked decrease in their performance score in the dual-task condition, particularly in the eyes closed condition. This is in line with previous studies suggesting that increased demands of proprioceptive processing may act in mobilizing attentional recourses (Yasuda et al., 2014).

Our study also developed a novel postural task, in which we were able to assess the functional stability limits of participants during a voluntary leaning task and a concurrent attentionally demanding cognitive task. This life-like paradigm will not only be useful in assessing the functional measures of participants, but will also pave the way for any future studies investigating the attentional demand of postural and cognitive measures in varying sensory conditions. Understanding the interaction between these keys aspects is crucial in the future development and implementation of fall prevention programs.

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Annexe 1

<u>CSEP-PATH: PHYSICAL ACTIVITY AND SEDENTARY</u>
<u>BEHAVIOUR QUESTIONNAIRE (PASB-Q) Adult (18 And over)</u>

Following the answers given for the following questions, the student-researcher will determine if the participant is considered sedentary.

<u>Aerobic physical activity</u>

1. Frequency: In a typical week, how many days do you do moderate-intensity (like brisk walking) to vigorous- intensity (like running) aerobic physical activity?

___days/week

2. Time or Duration: On average for days that you do at least moderate-intensity aerobic physical activity (as specified above), how many minutes do you do?

___minutes/day

Total: Multiply your average number of days per week by the average number of minutes per day.

___minutes/week

<u>Muscle strengthening physical activity</u>

3. In a typical week, how many times do you do muscle strengthening activities (such as resistance training or very heavy gardening)?

___times/week

Perceived aerobic fitness

4. In general, would you say that your aerobic fitness (ability to walk/run distances) is:

___Excellent ___Very Good ___Good ___Fair ___Poor

Sedentary Behaviour

5. On a typical day, how many hours do you spend in continuous sitting: at work, in meetings, volunteer commitments and commuting (i.e., by motorized transport)?

❒ None ❒ < 1 hour ❒ 1 to < 2 ❒ 2 to < 3

❒ 3 to < 4 ❒ 4 to < 5 ❒ 5 to < 6 ❒ > 6

6. On a typical day, how many hours do you watch television, use a computer, read, and spend sitting quietly during your leisure time?

❒ None ❒ < 1 hour ❒ 1 to < 2 ❒ 2 to < 3

❒ 3 to < 4 ❒ 4 to < 5 ❒ 5 to < 6 ❒ > 6

Total Sedentary Behaviour (add responses to questions 5 and 6) __hours/day

7. When sitting for prolonged periods (one hour or more), at what interval would you typically take a break to stand and move around for two minutes?

- ❒ < 10 minutes
- ❒ 10 to < 20 minutes
- ❒ 20 to < 30 minutes
- ❒ 30 to < 45 minutes
- ❒ 45 to < 1 hour
- ❒ 1 to < 1.5 hours
- ❒ 1.5 to < 2 hours
- ❒ > 2 hours

(CSEP, 2013)